ENVIRONMENTAL SERVICES
Greenhouse Gas Department

CERs MONITORING REPORT

Onyx Alexandria Landfill Gas Capture and Flaring Project

Alexandria, Egypt

(Registration number n° 508)

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Period 15th December 2006 to the 30th September 2007

Version 2

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1. Introduction

Onyx Alexandria, Subsidiary of Veolia Environmental Services (formerly Onyx) has developed the 'Onyx Alexandria Landfill Gas Recovery Project', which has been successfully registered by the Executive Board of the UNFCCC on the 15th December 2006.

According to the Project Design Document (PDD), the Crediting Period started at the date of the project registration, the 15th December 2006 for a period of 10 years. This monitoring report covers the emission reductions (ER) achieved by the site between the 15th of December 2006 and the 30th September 2007.

The monitoring report has been established according the approved methodology ACM 001 Version 2, referred to within the PDD.

TÜV SÜD, an accredited company for the sector 13, has been appointed as a Designated Operational Entity (DOE), in order to carry out the verification of the emission reductions achieved by the project activity for this period.

2. Project

2.1. Description

Veolia Environmental Services is proposing a Clean Development Mechanism project activity at its Alexandria landfill facility located in the villages of Borg El Arab and El Hammam, Alexandria, Egypt. The methane produced by the waste within the landfill is collected and is combusted through flares reducing the GhG emissions into the atmosphere.

The system at the Borg El Arab landfill site is fitted with a leachate evaporator system consisting of 2 evaporation units, which are not operational yet.

Two flares are installed at Borg El Arab landfill, however only one is running at a given time. The second flare has been commissioned the 3rd April 2007.

The flare at the El Hammam landfill started operation on the 1st August 2006. At a first stage, the instrumentation was not set as the adequate monitoring device was not designed yet. Periodic Manual records were taken during this period.

2.2. Project participants

Project participants for the CDM project are described below:

Veolia Environmental Services - 169 avenue Georges Clémenceau 92735 NANTERRE - FRANCE

Veolia Environmental Services - Onyx Alexandria for Complementary Services in Waste Treatment S.A.E. - Teleiba Street from Kabbary Road, Moharram Bek – Alexandria - Egypt

World Bank - 1818 H Street, NW - Washington, DC – 20433 - USA

3. Volume of CERs monitored

3.1. Baseline

The baseline approved within the PDD is the partial release to the atmosphere of the methane produced by the anaerobic degradation of waste.

The PDD, in accordance with the approved consolidated methodology ACM0001, defines an adjustment factor of 20% valid for the duration of the crediting period.

3.2. Project emissions

The project emissions are measured by metering the quantity of methane burned through the flare.
The table below provides the details of the emission reductions for both sites:

tCO2	Methane Combusted incl. Flare efficiency (tCO2eq)	Offset due to the baseline (20%)	unburnt flared methane associacted with the project (for information only)	Fuel Emission of the project activity	Emission reductions (tCO2e)
> 15 Dec 06	1 335	267	107	8	1 060
Jan-07	2 442	488	195	24	1 930
Feb-07	2 512	502	201	19	1 991
Mar-07	2 218	444	177	29	1 746
Apr-07	2 265	453	181	19	1 793
May-07	2 203	441	176	14	1 748
Jun-07	2 481	496	199	22	1 963
Jul-07	2 897	579	232	30	2 288
Aug-07	2 902	580	232	19	2 303
Sep-07	2 602	520	208	19	2 063
Oct-07	-	-	-	-	-
Nov-07	-	-	-	-	-
Dec-07	-	-	-	-	-
Total (CER)	**22 524,0**	**4 504,8**	**1 801,9**	**194,6**	**17 824,6**

The emission reductions achieved by the project are calculated based on the quantity of methane combusted minus the emissions associated with the project activity (gas oil auxiliary generator). An adjustment factor of 20% is applied to the emission reductions, as described in the PDD.

Consequently, the total amount of CERs claimed for the period from 15th December 2006 to the 30th September 2007 is **17 824,6 CERs.**

4. Monitoring methodology

4.1. Brief description

The ERs are reported in tonnes of CO_2 (tCO_2) and are calculated based on the instrumentation described within the PDD. The monitoring report is then based on the following devices:

- A flowmeter (Nm^3/hour) monitoring the landfill gas being burnt through the flare.
- A landfill gas analyser (%CH_4)
- The flare temperature (°C)

As the leachate evaporator units are not yet operational, it has not been equipped with monitoring instrumentation. However, the instrumentation will be installed in October 2007.

Different monitoring protocols were used during the period to integrate the maintenance and/or failure of equipment. The monitoring frequency evolves from one set of data per day to one set of data recorded every 5 minutes.

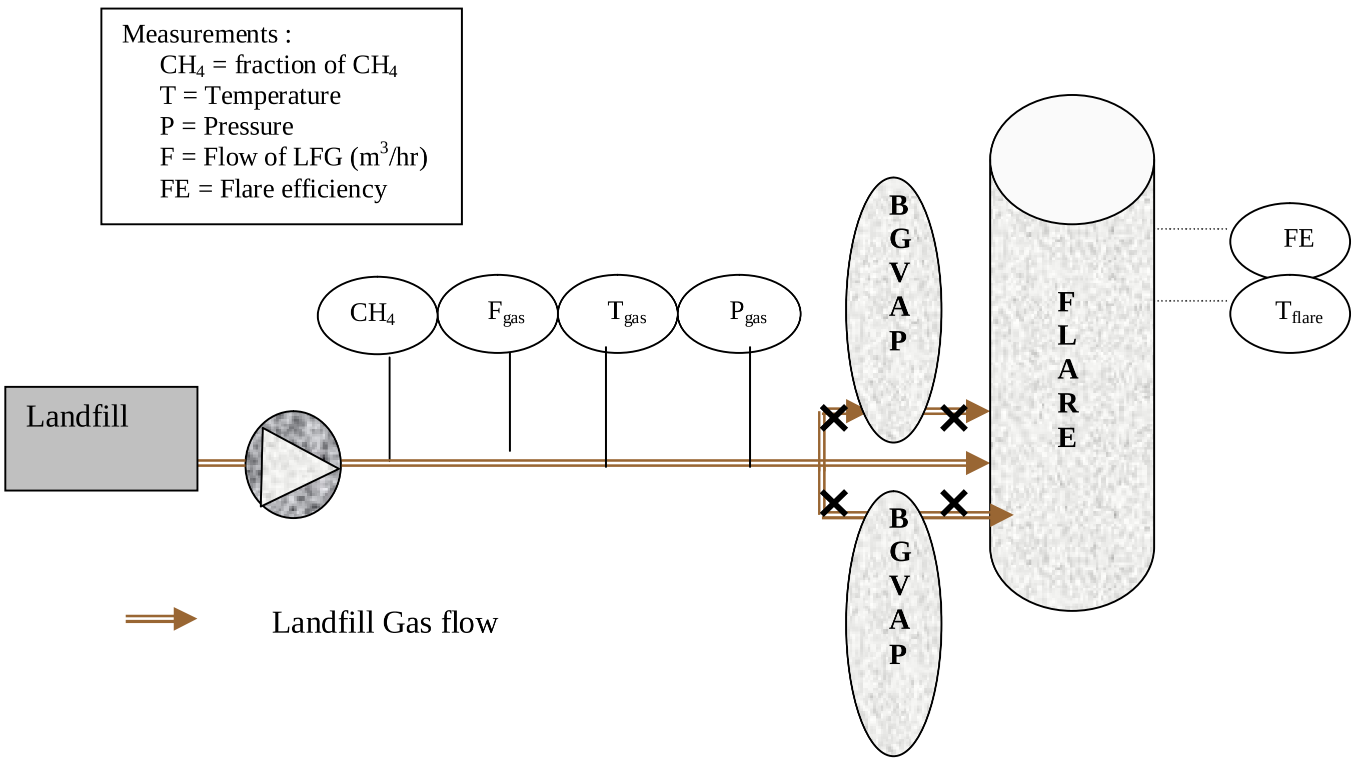
The gas flow and gas quality are aggregated monthly in order to calculate a normalised methane flow.

Manual readings were also recorded on a daily basis to complete the data recorded via the datalogger.

4.2. P&I Diagram

4.2.1. Borg El Arab

The diagram below represents the P&I Diagram of the Borg El Arab landfill.

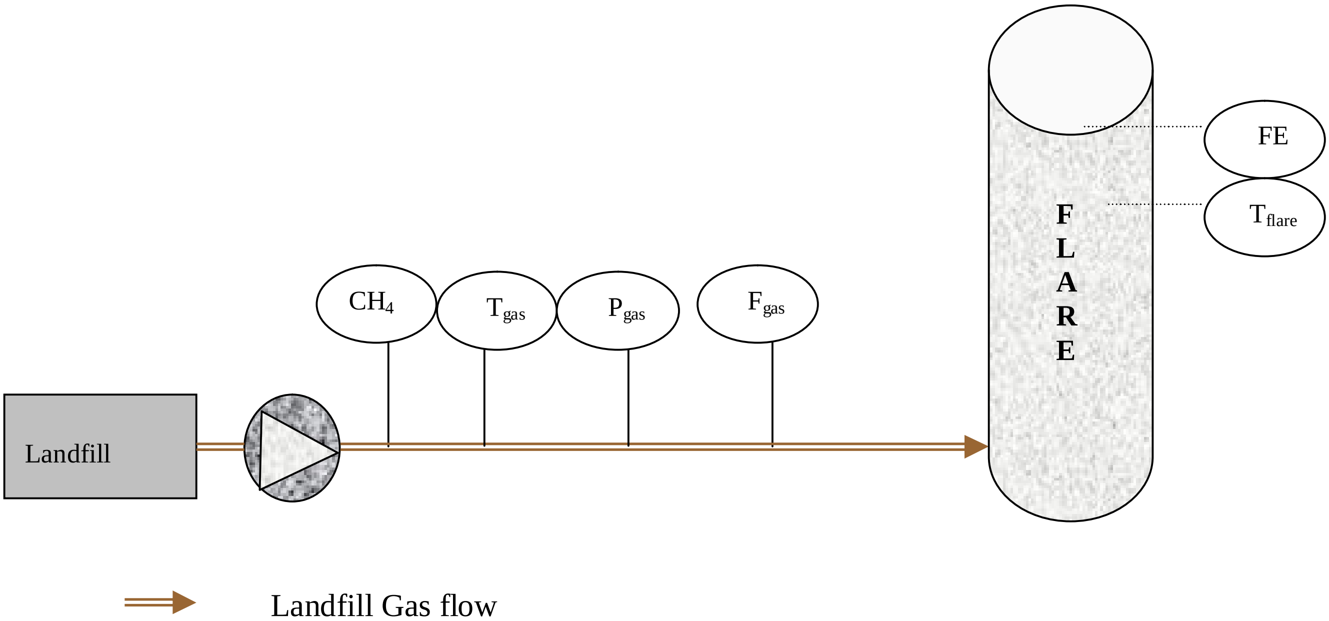


Although the leachate evaporator units are installed, they have not been re-commissioned yet. Consequently, no landfill gas has been combusted in this unit.

As part of the project activity, another flare has been installed onsite and commissioned on the 3rd of April 2007. Both flares have been equipped with the instrumentation as shown above. The flares are not running simultaneously.

4.2.2. El Hammam

The gas extraction and flaring unit have been installed in August 2006 at El Hammam. The system is described below:



4.3. Emission reduction calculation

The emission reduction calculation is based on the monitoring plan described in the PDD, Onyx Alexandria Landfill Gas Capture and Flaring Project, version 4.

The emission reductions are defined as the difference of emissions in the baseline situation and in the project situation.

$$ER_y = \left[\sum_{m=1}^{12} \left(\frac{\frac{0.016}{22.4} \sum_{t=1}^{N} LFG_{flare\,t,m} * W_{CH4\,t,m}}{Nm} \right) * RHm \right] * FE_{average} * (1 - AF) - C_{diesel} * CEF_{diesel}$$

Where,

ER_y is the quantity of emission reductions achieved in a given year y
$LFG_{flare, t, m}$ is the amount of landfill gas captured in Nm^3/hr and flared (and/or used within the leachate evaporator units) at the time t.
$W_{CH4t,m}$ is the concentration of methane in the landfill gas at the time of the month m
N_m is the number of data available during the given month.
RH_m is the number of hours during a given month
$FE_{average}$: Average of the flare efficiency test
AF is the adjustment factor to integrate the baseline emissions. AF is equal to 20% for this project throughout the crediting period.
C_{diesel} is the consumption of diesel for the electricity generator for the site.
CEF_{diesel} is the Conversion emission factor for the diesel.
0.016 = molecular weight methane (t/kmol)
22.4 = molecular volume at 0 °C and 1000 hPa (m^3/kmol)

$$\mathrm{LFG}_{\mathrm{flare,t,m}} = \mathrm{LFG}_{\mathrm{measured}} * \frac{P_{gas} * T_{normal}}{P_{normal} * T_{site}}$$

Where,
T_{normal} is the temperature is the reference temperature
P_{normal} is the reference pressure
P_{gas}: is the pressure of the gas
T_{gas} is the temperature of the gas

5. Data collection and analysis

5.1. Data collection principle

Every working day, data are recorded manually by a technician or a site engineer. In parallel, a data logger records the main parameters of the flare.

At El Hammam landfill, the data logger did not run correctly. Consequently, the data were recorded once a day from the start of the crediting period to the 31st of March. Then, the monitoring frequency increased to 9 set of records per day.

For Borg El Arab, the data logger was operational from the crediting period to the 31st of March. Then, periodic manual records where taken.

The manually recorded values were taken at a specific time, on a daily basis, by the flare operator.

5.2. Data analysis

Pressure, temperature and landfill gas flow are monitored in order to normalise the gas flow, following the equation below:

$$\mathrm{F}_{\mathrm{norm}} = \mathrm{F}_{\mathrm{measurred}} * \frac{293.14 * (P_{gas})}{1.013 * (273.15 + T)}$$

The number of running hours is directly monitored by a monitoring device and reported through daily log book.

At Borg El Arab, between the 15th December 2006 and the 31st of March 2007, the running hours are calculated from the data logger data (one set of data every 5 minutes). When no data are available the recorded running hours are used.

5.2.1. Data storage

Recorded data are archived within one file for each site:
- 'Monitoring data 07 EH vers 0.xls' for the El Hammam landfill
- 'Monitoring data BEA vers 0.xls' for the Borg El Arab landfill

6. Treatment of invalid data:

From time to time the instrumentation or the data logger can be in maintenance, faulty or down. This section provides the methodologies used to:
- Identify data requiring a manual check
- Correct data if required.

6.1. Identification of data requiring manual check

Data issued from the data logger are automatically checked with several coherence tests. If data fails one coherence check, it will be checked manually. The coherence tests are listed below:

- **Methane concentration:** If the methane concentration is below 20% or above 65%, the coherence test indicates the value 0, and 1 otherwise.
- **Flare temperature**: If the exhaust flare temperature is below 500°C or above 1500°C, the coherence test indicates the value 0, and 1 otherwise.
- **All data:** if the difference between 3 consecutive data is identical, the coherence test indicates the value 0, and 1 otherwise.

6.1.1. Facility status

A counter is installed at each facility in order to account for the running hours of the flare. This value is used during the crediting period, except for the month of December 2006 to March 2007, where the information from the datalogger could be used.

When data logger is used, flare operation is monitored through the flare stack temperature. The flare is considered burning landfill gas when the temperature is above 500°C.

6.1.2. Pressure at the flowmeter

The relative pressure of the LFG and the atmospheric pressure are monitored as the other parameters. In case of missing data the following conservative approach has been considered:

Pressure at the flowmeter is determined from the atmospheric pressure monitored at the Alexandria Airport. The landfill gas pressure at the flowmeter is slightly higher than the atmospheric pressure. A conservative approach is then to consider the lowest pressure.

Borg El Arab

The monitoring carried out from the 25/01/2007 to the 27/01/07 at Borg El Arab, shows that the relative pressure at the flowmeter is at all times lower than 5 mbar for the site. From a physical point of view the relative pressure cannot be negative. This has been confirmed by the regular monitoring of this parameter in 2007, where the relative pressure varies between 0.2 and 2.3 mbar from April to September 2007:

At El Hammam, a statistical study has been carried out from 28/01/07 to 30/01/07 . It shows that the relative pressure at the flowmeter is comprised between 0 and 10 mbar for the site. This has been confirmed by the regular monitoring of this parameter in 2007, where the relative pressure range from 1.20 to 9.1 mbar from April to September 2007 and the average is 7.15 mbar.

Consequently, in the absence of valid measurements, the most conservative value to be used is the atmospheric pressure. If no data for the atmospheric pressure is available on-site, the lowest daily value monitored at the nearby Alexandria airport will be used.

$P_{gas} = P_{atm} + P_{relative}$

Where:

P_{gas} is the absolute pressure at the Flowmeter

- Value recorded
- Or if no data available, the value is 0

P_{atm} is the atmospheric pressure

- Value recorded
- Or if not available, Lowest daily value monitored by the Alexandria airport

The atmospheric pressure historic for Alexandria airport is available on:
http://www.wunderground.com/history/airport/HEAX/2007/1/25/CustomHistory.html?dayend=30&monthend=1&yearend=2007&req_city=NA&req_state=NA&req_statename=NA

- $\mathbf{P}_{relative}$ is the measured relative pressure reading of the landfill gas at the flowmeter.

6.1.3. LFG Temperature at the flowmeter

The LFG temperature is used to normalise the landfill gas flow to be burnt within the flare.

Under normal operation conditions, LFG temperature is monitored. In the case, it is not available the highest valid value of the considered period is used.

Borg El Arab

The extraction and flaring unit is fitted with a temperature switch set at 80°C. It aims at protecting the blowers against over heating by shutting done the gas supply should this temperature be reached. It means that the landfill gas temperature never exceeds this temperature. The landfill gas temperature has been measured in 2007 during the hottest months of the year (between the first of April and the 9th of September). The maximum temperature observed was on the 6 and on the 8th of May, with 42.3°C, whereas the average

during the hot period is 26.2 °C. In order to be very conservative, a default LFG temperature of 42.3°C was used in the absence of recorded data.

El Hammam

The extraction and flaring unit is fitted with a temperature switch set at 80°C. It aims at protecting the blowers against over heating by shutting done the gas supply should this temperature be reached. It means that the landfill gas temperature never exceeds this temperature. In order to obtain a better estimate of the temperature of the landfill gas, the landfill gas temperature has been measured in 2007 during the hottest months of the year (between the first of April to the 9th of September). The maximum temperature recorded was on the 24/04/07, where the temperature reaches 89,3°C. During this period, the temperature switch/temperature gauge was not functioning properly. The problem has been fixed on the 28th of April 2007.
If this period is excluded (April month) due to a failure of monitoring equipment, the maximum temperature was reached on the 07/05/2007 with a maximum temperature of 50.4°C. This value is considered as conservative since the average landfill gas temperature observed between April and September 2007 was 33.2°C. It has been used in the absence of recorded data.

The flowmeters have been set up to provide a correct reading in normal condition at 20°C.

6.1.4. Flare efficiency

The efficiency of the flare was monitored though an analysis carried out on the 18 march 2007 at Borg el Arab and at el Hammam Landfill. The analysis was carried our by an independent laboratory (NCESOH). The result of the analysis shows that the flare efficiency ranges from 99.93 to 99.97 %.

The table below summarizes the main findings:

	BEA Flare 1	BEA Flare 2	El Hammam
Landfill Gas Inlet			
CH_4 %	29%	30.04%	37.005%
O_2 %	9.74%	9.94%	7.224%

Exhaust gas

$CH_4 (mg/m^3)$	17	28	14
O_2 %	10.2%	9.8%	9.7%

Flare Efficiency	**99.96 %**	**96.93 %**	**99.97 %**

The flare efficiency has been calculated applying the Tool to determine project emissions from flaring gases containing methane (EB28, Annex 13).

However, in order to comply with the recommendation of the EB, the default **efficiency factor of 90%** has been used.

6.2. Installation of additional monitoring equipment

In order to improve the reliability of the data records, new equipments are being installed on site. The equipments have been delivered on site week 42. The commissioning should be finalised in the next weeks.
The equipments include the replacement of all flowmeters by mass flowmeter which will be linked to internet-based datalogger system.
An orifice plate flowmeter is also being installed at Borg El Arab in order to totalise the landfill gas arriving at the facility.

Also the gas analyser is being replaced by a new gas analyser fitted with an auto calibration system allowing a continuous check and auto calibration at 0% methane and 50% methane.

All these new devices have been specially selected in order to work perfectly with an internet based datalogger. Data will be retrieved continuously by each device and on periodic and automatic way they will be sent through a server file. This new feature should improve the data collection, data storage and data analysis.

6.3. Invalid data

At the El Hammam site between December 2006 and March 2007:

When the data logger failed to provide correct reading and it exists a mean to justify the flare operation the following methods have been used in order to calculate the emission reductions.

When the CH4 readings are invalid or missing the manual daily readings are used. When no daily readings are available but the status of the flare is known the monthly average is used.

In any case, the running hours of the flare are registered, providing an evidence of the status of the flare. This method allows to strictly applying the formulae of the monitoring plan described within the PDD.

At Borg El Arab between December 2006 and March 2007

The existing datalogger which shall be replaced in the coming weeks fails sometimes to register the data properly. Coherence checks have been designed and applied to detect all the record anomalies.

Data not issued from a direct measure from the data logger (data extrapolated) are substituted by a monthly average value.

7. Statistical analysis of manual and data logger readings:

7.1. Background

Originally the monitoring was intended to be performed through a data logger which would have provided a measurement every five minutes, twenty four hours per day. As described above, this system did however not operate correctly and periodical manual readings of the main parameters were taken additionally – including the concentration of methane in the biogas (CH4%) and the landfill gas flow (LGF).

As a result of the problems with the data logger at both sites, the following series of data are available for each of the two landfill sites:

"Borg El Arab" - the data logger has worked properly for a limited period of time:
- 15 December 2007 to 31st March: data logger properly working – 288 data/day;
- 1st April 2007 to 30 September 2007: manual readings – 9 data/day;

"El Hamman" - the data logger has never worked properly:
- 15 December 2007 to 31st March: manual readings – 1 data/day;
- 1st April to 30 September 2007: manual readings – 9 data/day

7.2. Request from the EB

As a consequence of the above, the CDM Executive Board decided to demand additional statistical analysis of the data (see EB39):

" 71. The Board agreed to instruct the CDM registry administrator to issue CERs, subject to satisfactory corrections, for "Onyx Alexandria Landfill Gas Capture and Flaring Project" (0508) for the monitoring period 15 December 2006 - 30 September 2007 if the project participant and the DOE (TÜV-SÜD) if the PP/DOE submit a revised monitoring report and a revised verification report and a new request for issuance, as appropriate, which include:

(a) A statistical analysis, which should include specifying the null hypothesis to be tested and how the variances/standard deviation for the different data sets are calculated and compared, and the justification on the appropriateness of the test for the project situation;

(b) The assessment on how the test confirms that for each site and for each period with different monitoring frequency, the periodical measurements of the fraction of methane in the landfill gas are at a 95% confidence level."

7.3. Statistical analysis

As demanded by the Executive Board, statistical analysis of the data sets from the two sites (Borg el Arab and El Hammam) was performed and one report for each site was issued by separate statisticians – see Annex 2 and 3. The aim of these analysis, was to show that the

periodicity of the manual readings guarantee comparability with continuous (data logger) readings and provide an uncertainty not higher than 10% at a 95% confidence level.

The uncertainty level was thereby chosen in a conservative manner on the basis of a recommendation of the Meth Panel (“Proposed guidance on addressing bias uncertainty”) which states an uncertainty of 15%.

As described in the reports in the annex, the statistical approach chosen was the Student t test, its applicability was proved during the analysis.

For Borg El Arab the analysis was based on data from the data logger between 15th of December 2006 and the 31st of March 2007 (readings every 5 minutes, 288 daily) compared to 9 manual readings daily from the same period (recorded hourly between 7:00 and 15:00).
The result of the statistical test is that the 9 measures per day are enough to guarantee an uncertainty not higher than 10% at a 95% confidence level.

For El Hamman the analysis was based on data from the data logger between March 2008 and July 2008 (readings every 5 minutes, 288 daily) compared to 9 manual readings daily from the same period (recorded hourly between 7:00 and 15:00) in a first case and one single manual reading daily (randomly chosen between 7:00 and 15:00) in a second case. This period was chosen as it is the first period in which 288 data/day are available within the whole project history.
The result of the statistical test is that both 9 measures per day and also 1 measure per day are enough to guarantee an uncertainty not higher than 10% at a 95% confidence level.

ANNEX 1

The Diesel oil emission factor has been calculated as follows

Diesel oil	tCO2/TJ	74,1	2006 IPCC Guidelines for national Greenhouse Gas Inventories, Volume 2, section 2, P16
Diesel Oil	kJ/kg	43 000	2006 IPCC Guidelines for national Greenhouse Gas Inventories, Volume 2, section 1, P18
Diesel oil density max	kg/L	0,8516	Special Issues Paper 9; 2004, http://www.iea.org/Textbase/work/2004/eswg/SIP9.pdf,
Diesel Emission factor	kCO2/L	2,713	Calculated from the above

The atmospheric pressure historic for Alexandria is available on:
http://www.wunderground.com/history/airport/HEAX/2007/1/25/CustomHistory.html?dayend=30&monthend=1&yearend=2007&req_city=NA&req_state=NA&req_statename=NA

ANNEX 2

CENTRE DE RECHERCHE SUR LA PROPRETE & L'ENERGIE

PERIODICAL SAMPLING UNCERTAINTY ON BIOGAS METHANE FRACTION ESTIMATION "Onyx Alexandria Landfill Gas Capture and Flaring Project"

MARTINEZ Xabier
04/07/08

Abstract:

According to the consolidated baseline methodology for landfill gas project activities (ACM0001), the average methane fraction of the landfill gas (Wch4,y) should be measured with a continuous analyzer or, alternatively with periodical measurements at 95% confidence level. The actual statistical analysis will test whether the uncertainty of periodical measurements consisting on nine samples per day exceeds 10 % (at 95% confidence level).

Diffusion	CC :
BONDOIS, Lionel	ARAN, C.
CRAWFORD, Gary	MOUQUET, D.

1. CONTEXT

The "Onyx Alexandria Landfill Gas Capture and Flaring Project" accounts for Greenhouse gas emission reduction resulting from gas flaring (permitting the conversion of methane into carbon dioxide).

The methodology for landfill gas project activities (ACM0001), suggests that the methane fraction of the landfill gas should be measured with a continuous analyzer or, alternatively with periodical measurements. In the last case, the executive board of the project demands for justification of the subsequent uncertainty at 95% confidence level.

As a result of data logger operational problems in the landfill of "Borg el Arab", the methane fraction monitoring had to be implemented alternatively. The actual statistical analysis has been carried out in order to account for the uncertainty level from the non-continuous measurements and to respond to the following EB request:

"

(a) A statistical analysis, which should include specifying the null hypothesis to be tested and how the variances/standard deviation for the different data sets are calculated and compared, and the justification on the appropriateness of the test for the project situation.

(b) The assessment on how the test confirms that for each site and for each period with different monitoring frequency, the periodical measurements of the fraction of methane in the landfill gas are at a 95% confidence level."

In the absence of EB recommendation on the null hypothesis, a conservative approach compare to the recommendation of the Meth Panel of the '**Proposed guidance on addressing bias uncertainty:'** has been taken. This proposed guideline mentions:

> *If the random uncertainty of overall emission reductions of the project activity does not exceed 15% (at a 95% confidence level), no further action to deal with random uncertainty is required.*

Consequently, the statistical analysis will test if the uncertainty of the methane fraction measurement does not exceed 10% at a 95% confidence level. This test is more conservative than the meth panel recommendations.

2. OBJECTIVESS

Let be "µa" the expected value of the methane fraction from the periodical measurements and "µref "the expected value of continuous measurements (reference expected value). We consider the conformity of the periodical measurements by the following test:

H0 (Null hypothesis): $(\mu a - \mu ref) / \mu ref > p_0$
H1 (Alternative hypothesis): $(\mu a - \mu ref) / \mu ref < p_0$ [0]

Where, p_0 is the uncertainty limit. Here it is set at 10%.

H0: The difference between the expected methane fraction of periodical measurements and the expected value from continuous measurements exceeds p_0 (for instance 10%).
H1: The difference between the expected methane fraction of periodical measurements and the expected value from continuous measurements does not exceed p_0 (for instance 10%).

A statistical test result leading to H0 rejection (and H1 acceptation) will prove that the uncertainty from periodical sampling does not exceed "p_0".

The statistical test will be conservative, since in case of sub-estimation of the methane fraction from periodical measurements, the H0 hypothesis will tend to be rejected, and the method will be considered adequate.

The conformity of the following scenario will be tested:

1) Alternative method (Periodical measurements):

- Nine measurements per day between 7:00 am and 15:00 pm.

2) Reference method (Continuous measurements): One measurement each five minutes.

3. METHODOLOGY

3.1.- Definitions :

Let be two sampling methodologies for methane fraction monitoring:

a) Alternative method: Periodical measurements of « N » samples per day between 7:00 am and 15:00 pm.

b) Reference method: Continuous measurements: One measurement each five minutes.

3.2.- Assessment of daily means for methane fraction

Let consider "J" randomly selected days in the studied period (for instance between December and April 2007)

For the "i"-th day (i = 1, ...J), we can define the following **paired parameters**:

Let $W_{A,i}$ be the weighted mean for the methane fraction in the day « i », measured by the alternative method (A method, periodical measurement of N samples per day).

$$W_{A,i} = \frac{\sum_{k=1}^{N} (LFG_{flare,k} * W_k)}{\sum_{k=1}^{N} LFG_{flare,k}} \quad \text{For} \quad k = 1, \ldots N \qquad [1]$$

Where,

N = Number of samples per day according to the alternative method (« A » method).
$LFG_{flare,k}$ = Gas flow (in Nm3/h) for the « k »- th sample.
W_k = Methane fraction (%) for the « k »-th sample.
$W_{A,i}$ = Weighted daily mean for methane fraction measured by the alternative method (« A ») in the day « i ».

Let $W_{B,i}$ be the weighted mean for the methane fraction in the day « i » measured with the reference method (REF method)-

$$W_{B,i} = \frac{\sum_{j=1}^{Mi} (LFG_{flare,j} * W_j)}{\sum_{j=1}^{Mi} LFG_{flare,j}} \qquad \text{Pour j = 1, …M} \qquad [2]$$

Where,

Mi = Non – missing data number in the day « i » (reference method, « REF »). Mi value is about 288 which corresponds to the measurements each five minutes.
$LFG_{flare,j}$ = Gas flow (in Nm3/h) for the « j »-th sample.
W_j = Methane fraction (%) for the « j »-th sample.
$W_{B,i}$ = Daily weighted mean for methane fraction measured from dataset coming from de reference method (« REF ») in the day « i ».

$W_{A,i}$ and $W_{B,i}$ are the weighted mean values of methane fraction for the periodical measurements and for the continuous measurements respectively. **Both are paired in the day « i ».**

3.3.- Expected value of the methane fraction in the studied period

3.3.1.- A method (periodical measurements of N samples per day).

Let μ_a be the expected value of the methane fraction in the studied period from the dataset of A method (N samples per day):

$$\hat{W}_A = \frac{\sum_{i=1}^{J}\sum_{k=1}^{N} LFG_k * Wk}{\sum_{i=1}^{J}\sum_{k=1}^{N} LFG_k} = \frac{\sum_{i=1}^{J} C_{Ai} * W_{A,i}}{J} = \frac{\sum_{i=1}^{J} W'_{A,i}}{J} \qquad \text{Pour i = 1,…J et k=1,…N.} \qquad [3]$$

Where,
C_{Ai} = Weighting coefficient for the "i" – th day and for the « A » method.

$$C_{Ai} = \frac{\hat{LFG}_{A\,i}}{LFG_{AT}} \qquad [4]$$

LFG_{Ai} = Mean biogas flow in the day « i » (measured from N values).
LFG_{AT} = Weighted mean of biogas flow in within the period of J days (Measured from N*J values).
i = The day.
J = Day number in the studied period.
k = Sample within the day.
N = Number of samples per day according to the « A » method.

The expected methane fraction can be assessed on the basis of the daily means. For this, we must weight the daily means ($W'_{Ai} = C_{Ai}*W_{Ai}$). The expected methane fraction will be estimated simply by measuring the arithmetic mean of the corrected values (W'_{Ai}). Therefore,

$$\mu_a = E(C_{Ai}*W_{Ai}) = E(W'_{Ai}) \qquad [5]$$

3.3.2.- Reference method (REF, with about 288 samples per day)

Let μ_{ref} be the expected value of the methane fraction in the studied period from the dataset of REF method (continuous measurements).

$$\hat{W}_{Ref} = \frac{\sum_{i=1}^{J}\sum_{j=1}^{Mi} LFG_j * Wj}{\sum_{i=1}^{J}\sum_{j=1}^{Mi} LFG_j} = \frac{\sum_{i=1}^{J} C_{REFi} * W_{REF,i}}{J} = \frac{\sum_{i=1}^{J} W'_{REF,i}}{J} \quad \text{For i = 1,…J and j = 1,…Mi.} \qquad [6]$$

Being,
i = the day in the period.
J = the day number within the studied period.
j = the sample in the day (one sample each five minutes).
Mi = the sample number per day according to REF method (being Mi about 288)
C_{REFi} = weighting coefficient for the « i »th day.

$$C_{REFi} = \frac{\hat{LFG}_{REFi}}{LFG_{REFT}} * \frac{Mi}{\hat{M}} \qquad [7]$$

LFG_{REF}i = mean gas flow in the "i"-th day (assessed from Mi values)
LFG_{REFT} = weighted mean of the gas flow in the studied period.
M^= mean number of non-missing values per day (268-288)

Then, the daily means of the methane fraction can be used in order to assess the expected value of the methane fraction in the period. For this, we must weight Wrefi values to obtain W'refi (**$W'_{refi} = C_{refi}*W_{refi}$**). The expected methane fraction in the studied period is simply estimated from the arithmetic mean of **W'_{refi}**.

$$\mu_{ref} = E(C_{refi}*W_{refi}) = E(W'_{refi}) \qquad [8]$$

3.4.- Statistical test

According to the hypothesis in [0]:

H0 (Null hypothesis) : $\mu_a - \mu_{ref} > p_0*\mu_{ref}$
H1: $\mu_a - \mu_{ref} < p_0*\mu_{ref}$ [9]

The conformity of the alternative method (A method) will be proved if the null hypothesis (H0) is rejected.

Developing the expression in H0 :

$\mu_a - \mu_{ref} > p_0*\mu_{ref}$;
$\mu_a - \mu_{ref} - p_0*\mu_{ref} > 0$;
$\mu_a - (1+p_0)*\mu_{ref} > 0$;

Being "p_0" a constant value, we can asses "di" for each day, as follows:

$$di = W'_{A,i} - (1+p_0)*W'_{REF,i}. \qquad [10]$$

Where, $W'_{A,i}$ and $W'_{REF,i}$ are the weighted daily means of the methane fraction (cf. [8] et [5])

As we can see the expected value of mean differences equals the expected value of "di":

$$\mu_d = E(di) = E(W'_{A,i} – (1+p_0)^* W'_{REF,i}) = E(W'_{A,i}) – (1+p_0)^*E(W'_{REF,i}) = \mu_a – (1+p_0)^*\mu_{ref} \quad [11]$$

For instance, when p_0=10%=0.1, (testing for uncertainty exceeding 10%):

$\mu d = E(di) = \mu a – 1{,}1^*\mu ref$

We can then simplify the expression in [9], and test in their place the following hypothesis:

H0 (Null hypothesis) : $\mu d >= 0$ [12]
H1 : $\mu d < 0$

H0 : $(\mu a – \mu ref)/\mu ref > 0.1 \rightarrow \mu a – 1.1^*\mu ref > 0 \rightarrow \mu d > 0$

In order to verify the conformity of « A » method, the null hypothesis must be rejected (H0 rejected and H1 accepted).

These hypotheses will be tested by a Student T test on "di" values.

3.5.- The « Student T » test on « di » values

Let $W'_{A,i}$ and $W'_{REF,i}$ be the mean methane fraction in the « i »-th day, measured by the A and REF methods respectively.

Being $W'_{A,i}$ and $W'_{REF,i}$ paired in the day « i », we can assess the « di » value as follows :

di = $W'_{A,i} - (1+p_0)* W'_{REF,I}$. For instance if $p_0 = 10\%$, di = $W'_{A,i} - 1{,}1* W'_{REF,I}$

Where, "di" represents the difference between de daily means of methane fraction with A and REF methods respectively. This value is adapted to test the hypotheses in [0].

Hypotheses (« left sided test »):

H0 : µd >= 0
H1 : µd < 0

Student « t » coefficient :

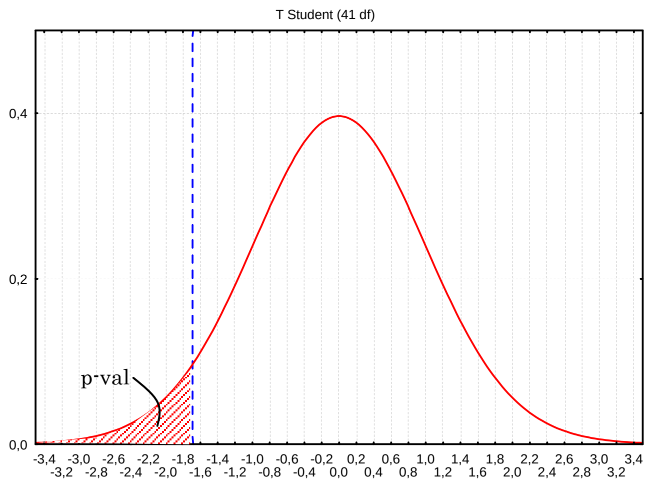
$$t = \frac{\hat{d} - 0}{s / \sqrt{J}} \qquad [13]$$

Where,

d^ = Mean of di
s = Standard deviation of di

$$s = \sqrt{\frac{\sum_{i=1}^{J}(di - \hat{d})}{J-1}} \qquad [14]$$

Decision :
Null hypothesis (H0) will be rejected if the left sided p-value of a Student « t » distribution, with J-1 degrees of freedom is lower than 0.05 ($\alpha = 0.05$, and so the test is performed at a 95% confidence level).



3.5.- « Student t » test validation :

Student « t » test is adapted to normally distributed random variables. Normality of “di” values will be tested by Shapiro Wilks test.

4. RESULTS

STATISTICAL TEST ON THE UNCERTAINTY OF EXPECTED "W_{CH4}" VALUE IN PERIODICAL MEASUREMENTS ("BORG EL ARAB")

Analysed scenarios:

Uncertainty < 10%

Alternative method ("A"): N=9 measurements per day from 7:00 am to 15:00 (each hour)
Reference method ("REF"): One data each five minutes (0-24h)

H0 : (μa – μref)/μref >= 0.1 ≡ H0 : μd >= 0
H1 : (μa – μref)/μref < 0.1 ≡ H1 : μd < 0

Results:

W, METHANE FRACTION (%). Test on uncertainty limit		
REF (Continuous measurements)	*A METHOD (Periodical measurements)*	
		p_0 = 10%
		N=9
Wch4 (Weighted mean)	37,5	39,0
Error (%) 100(Wa-Wref)/Wref*	-	3,8
Mean (di)	-	-2,3
Variance (di)	-	5,9
J (Day number in the studied period)	41	41
Student T statistic	-	-6,3
df	-	42
p-value	-	0,000
conclusion	-	H0 rejected

For $H0 : (\mu_a - \mu_{ref})/\mu_a > p_0$
$H1 : (\mu_a - \mu_{ref})/\mu_a < p_0$

Then,

The sampling uncertainty of periodical measurements consisting on N=9 per day is lower than 10% (at 95% confidence level) in the studied period.

T Student test validation: Normality

The Student T is adapted to normally distributed data. The results of normality tests are showed bellow according to

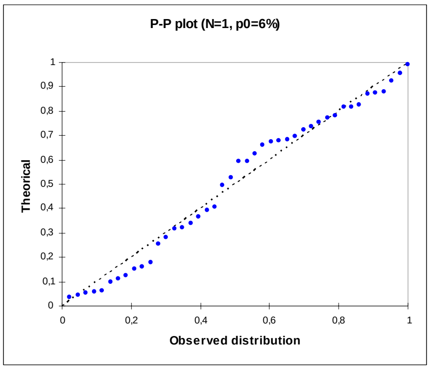
- Shapiro Wilks test.
- Anderson-Darling
- Lilliefors
- Jarque-Bera

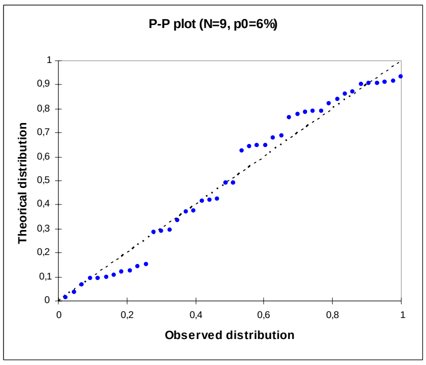
Normality tests on « di » values:

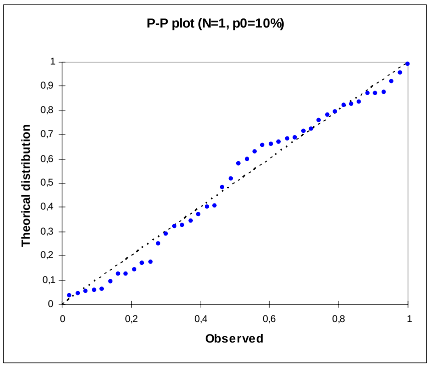
NORMALITY TESTS RESULTS ON « di » values	SCENARIO
	N=9(p_0=10%)
Shapiro Wilks	
W	0,954
p-value	0,084
Conclusion	H0
Anderson-Darling	
A^2	0,627
p-value	0,096
Conclusion	H0
Lilliefors	
D	0,113
D (norm)	0,741
p-value	0,182
Conclusion	H0
Jarque-Bera	
JB (obs)	2,559
JB (critical value)	5,991
DDL	2
p-value	0,278
Conclusion	H0

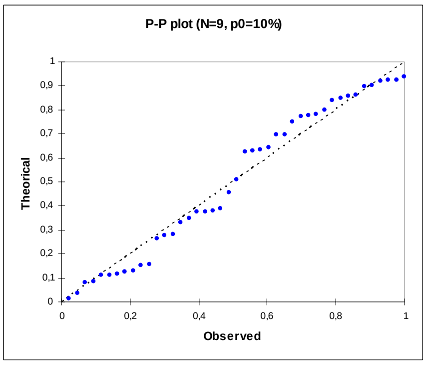
Hypothesis :
H0 : The sample data are normally distributed.
Ha : The sample data are not normally distributed.

Then, we can consider the « di » data as normally distributed.









5. CONCLUSIONS FOR PERIODICAL SAMPLING UNCERTAINTY IN « BORG EL ARAB » DATASET

According to the performed statistical tests in the studied period (December 2006 – April 2007):

The sampling uncertainty on methane fraction estimation is lower than 10% (at 95% confidence level) for periodical measurements of N=9 data per day. Where N=9, measured between 7:00 am and 15:00 pm (1 measured per hour).

6. REFERENCES

Gopal K. Kanji (2006): 100 Statistical tests, 3. Sage, London. 239p.
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Thode H.C. (2002). Testing for normality. Marcel Dekker, New York, USA.

ANNEX I :

SELECTED DAYS (MISSING VALUES <20) « BORG EL ARAB » DATASET

day	NonMissing data number	Selected
16/12/2006	124	FALSE
17/12/2006	271	FALSE
18/12/2006	178	FALSE
19/12/2006	277	TRUE
20/12/2006	227	FALSE
21/12/2006	280	TRUE
22/12/2006	284	TRUE
23/12/2006	283	TRUE
24/12/2006	173	FALSE
25/12/2006	1	FALSE
26/12/2006	137	FALSE
27/12/2006	286	TRUE
28/12/2006	259	FALSE
29/12/2006	229	FALSE
30/12/2006	13	FALSE
31/12/2006	149	FALSE
01/01/2007	285	TRUE
02/01/2007	173	FALSE
03/01/2007	38	FALSE
04/01/2007	137	FALSE
05/01/2007	276	FALSE
06/01/2007	275	TRUE
07/01/2007	276	TRUE
08/01/2007	284	TRUE
09/01/2007	279	TRUE
10/01/2007	288	TRUE
11/01/2007	280	TRUE
12/01/2007	288	TRUE
13/01/2007	279	TRUE
14/01/2007	253	FALSE
15/01/2007	196	FALSE
16/01/2007	187	FALSE
17/01/2007	284	TRUE
18/01/2007	288	TRUE
19/01/2007	282	FALSE
20/01/2007	280	TRUE
21/01/2007	215	FALSE
22/01/2007	175	FALSE
23/01/2007	134	FALSE
24/01/2007	282	TRUE
25/01/2007	276	TRUE
26/01/2007	286	TRUE
27/01/2007	280	TRUE
28/01/2007	278	TRUE
29/01/2007	277	FALSE
30/01/2007	284	TRUE
31/01/2007	276	FALSE
01/02/2007	272	FALSE
02/02/2007	288	TRUE
03/02/2007	281	TRUE
04/02/2007	288	TRUE
05/02/2007	288	TRUE
06/02/2007	288	TRUE
07/02/2007	286	TRUE
08/02/2007	283	FALSE
09/02/2007	286	TRUE
10/02/2007	280	FALSE
11/02/2007	288	TRUE
12/02/2007	284	FALSE
13/02/2007	224	FALSE
14/02/2007	194	FALSE
15/02/2007	287	TRUE
16/02/2007	283	FALSE
17/02/2007	286	TRUE
18/02/2007	287	TRUE
19/02/2007	277	FALSE
20/02/2007	288	TRUE
21/02/2007	187	FALSE
22/02/2007	168	FALSE
23/02/2007	284	FALSE
24/02/2007	280	TRUE
25/02/2007	282	TRUE
26/02/2007	283	FALSE
27/02/2007	286	TRUE
28/02/2007	277	TRUE
02/03/2007	188	FALSE
03/03/2007	261	FALSE
04/03/2007	270	TRUE
05/03/2007	281	TRUE
06/03/2007	287	TRUE
07/03/2007	288	TRUE
08/03/2007	196	FALSE
09/03/2007	117	FALSE
10/03/2007	107	FALSE
11/03/2007	1	FALSE
13/03/2007	53	FALSE
19/03/2007	245	FALSE
20/03/2007	232	FALSE
21/03/2007	173	FALSE
23/03/2007	179	FALSE
24/03/2007	228	FALSE
25/03/2007	85	FALSE
26/03/2007	144	FALSE
27/03/2007	230	FALSE
28/03/2007	203	FALSE
29/03/2007	265	FALSE
30/03/2007	257	FALSE
31/03/2007	221	FALSE

ANNEX 3

To: Lionel Bondois
From: Dr. Nikita Kuksin

Subject: Analysis of the Robustness of Alternative Monitoring Methods at El Hammam Landfill Site

Abstract:

According to the consolidated baseline methodology for landfill gas project activities (ACM0001), the average methane fraction of the landfill gas (Wch4,y) should be measured with a continuous analyzer or, alternatively with periodical measurements at 95% confidence level. The actual statistical analysis will test whether the uncertainty of periodical measurements consisting on nine samples per day exceeds 10 % (at 95% confidence level).

1 CONTEXT

The "Onyx Alexandria Landfill Gas Capture and Flaring Project" accounts for Greenhouse gas emission reduction resulting from gas flaring (permitting the conversion of methane into carbon dioxide).

The methodology for landfill gas project activities (ACM0001), suggests that the methane fraction of the landfill gas should be measured with a continuous analyzer or, alternatively with periodical measurements. In the last case, the executive board of the project demands for justification of the subsequent uncertainty at 95% confidence level.

As a result of data logger operational problems in the landfill of "El Hammam", the methane fraction monitoring had to be implemented alternatively. The actual statistical analysis has been carried out in order to account for the uncertainty level from the alternative monitoring methodologies implemented at El Hamam Landfill Site:

- One records per day
- Nine records per day

This statistical analysis aims to respond to the following EB request:

"

(a) A statistical analysis, which should include specifying the null hypothesis to be tested and how the variances/standard deviation for the different data sets are calculated and compared, and the justification on the appropriateness of the test for the project situation.

(b) The assessment on how the test confirms that for each site and for each period with different monitoring frequency, the periodical measurements of the fraction of methane in the landfill gas are at a 95% confidence level.''

In the absence of EB recommendation on the null hypothesis, a conservative approach compare to the recommendation of the Meth Panel of the 'Proposed guidance on addressing bias uncertainty:' has been taken. This proposed guideline mentions:

If the random uncertainty of overall emission reductions of the project activity does not exceed 15% (at a 95% confidence level), no further action to deal with random uncertainty is required.

Consequently, the statistical analysis will test if the uncertainty of the methane fraction measurement does not exceed 10% at a 95% confidence level. This test is more conservative than the meth panel recommendations.

2 SETUP

Let μ_M be the expected value of methane concentration obtained using some measurement method M, and let μ_{ref} be the expected value obtained using continuous measurements (below referred to as "reference measurement method"). We evaluate the quality of periodic measurements using the following test:

$$\begin{aligned} &H_0 \text{ (Null hypothesis)}: \quad \frac{\mu_M - \mu_{ref}}{\mu_{ref}} \geq p_0 \\ &H_1 \text{ (Alternative hypothesis)}: \quad \frac{\mu_M - \mu_{ref}}{\mu_{ref}} < p_0, \end{aligned} \tag{1}$$

where p_0 is the uncertainty limit, set at 10%.

The null hypothesis H_0 states simply that the relative difference between the expected concentration of methane obtained using periodic measurements and the expected concentration obtained using continuous measurements exceeds p_0.

The alternative hypothesis H_1 states that the relative difference between the two expected concentrations of methane does not exceed p_0, making the method M acceptable.

Since statistical tests allow to make a decision concerning the possibility of rejecting the **null** hypothesis, the aim of the test presented in this study is to evaluate H_0 as formulated above. The rejection of H_0 will support the belief that the imprecision arising from discrete measurements does not exceed the required maximum.

The particular setup of the test in (1) implies that if the concentration of methane is under-estimated, the null hypothesis will tend to be rejected, and the corresponding method will be considered adequate.

3 METHODOLOGY

3.1 Definitions

In what follows, two methods will be tested to evaluate their performance relative to the reference method:

1) **Alternative Method 1** (*AM*1 – periodical measurements): nine measurements are taken at regular points in time between 7:00 and 15:00.
2) **Alternative Method 2** (*AM*2 – random measurement): a single measurement is taken at a random point in time between 7:00 and 15:00.

The reference method is implemented by measuring the concentration of methane every five minutes, which leads to 288 daily observations.

3.2 Assessment of Daily Averages for Methane Concentration

Consider J selected days in the studied period (March to July 2008). For the i-th day, with $i = 1,\ldots, J$, we define W_i^M as the weighted average of methane concentration for the i-th day obtained using the method M (either one of the two alternative methods, or the reference method):

$$W_i^M = \frac{\sum_{k=1}^{N}\left(LFG_{k,i}^{flare} \cdot W_{k,i}\right)}{\sum_{k=1}^{N} LFG_{k,i}^{flare}}, \qquad i = 1,\ldots, J \tag{2}$$

where

- N is the number of samples per day chosen according to the particular method used;
- $LFG_{k,i}^{flare}$ is the total flow (cubic meters per hour) of the landfill gas observed at the k-th measurement during the i-th day;
- $W_{k,i}$ is the concentration of methane observed at the k-th measurement during the i-th day.

3.3 Expected Methane Concentration in the Studied Period

The estimation of methane concentrations is done in a completely analogous manner for the three methods. Below a detailed exposition of the procedure is given, using $AM1$ as an example.

3.3.1 Method $AM1$

Let μ_{AM1} be the expected value of methane concentration in the studied period. It can be empirically estimated using the weighted average introduced above:

$$\hat{\mu}_{AM1} = \frac{\sum_{i=1}^{J}\sum_{k=1}^{N}\left(LFG_{k,i}^{flare} \cdot W_{k,i}\right)}{\sum_{i=1}^{J}\sum_{k=1}^{N} LFG_{k,i}^{flare}} = \frac{\sum_{i=1}^{J} C_i^{AM1} \cdot W_i^{AM1}}{J} = \frac{\sum_{i=1}^{J} \widetilde{W}_i^{AM1}}{J}, \tag{3}$$

where C_i^{AM1} is the weighting coefficient for the i-th day using method $AM1$:

$$C_i^{AM1} = \frac{\sum_{k=1}^{N} LFG_{k,i}^{flare}}{\frac{1}{J}\sum_{i=1}^{J}\sum_{k=1}^{N} LFG_{k,i}^{flare}} \quad \left(= \frac{MeasuredDailyFlow}{AverageDailyFlow}\right).$$

The expected concentration of methane can be assessed on the basis of such daily averages. First, each daily average (see (2)) is weighted by the corresponding relative daily flow of gas $\widetilde{W}_i^{AM1} = C_i^{AM1} \cdot W_i^{AM1}$. Then, the expected concentration of methane can be estimated using the conventional arithmetic mean of weighted values:

$$\mu_{AM1} = \mathrm{E}\left[C_i^{AM1} \cdot W_i^{AM1}\right] = \mathrm{E}\left[\widetilde{W}_i^{AM1}\right].$$

3.4 Statistical Test - Formulation

Using the definition of the two hypotheses given in (1), the test can be reformulated as

$$\begin{aligned} &H_0 \text{ (Null hypothesis)}: \quad \mu_M - \mu_{ref} \geq p_0 \cdot \mu_{ref} \\ &H_1 \text{ (Alternative hypothesis)}: \quad \mu_M - \mu_{ref} < p_0 \cdot \mu_{ref} \end{aligned} \qquad (4)$$

Where as before a particular method M will be seen as acceptable if the null hypothesis can be rejected.

The expression in H_0 can be developed a little further:

$$\mu_M - (1 + p_0) \cdot \mu_{ref} > 0 \,. \qquad (5)$$

Since p_0 is simply a constant, and true expectations μ_M and μ_{ref} are replaced by their empirical estimates from (3), for each day $i = 1,\ldots, J$ a new variable can be defined as follows:

$$d_i^M = \widetilde{W}_i^M - (1 + p_0) \cdot \widetilde{W}_i^{ref} \,. \qquad (6)$$

The usefulness of d_i^M arises first of all from the fact that its expected value equals the weighted difference of expected methane concentrations introduced in (5):

$$\mu_d = E\left[\widetilde{W}_i^M - (1 + p_0) \cdot \widetilde{W}_i^{ref}\right] = E\left[\widetilde{W}_i^M\right] - (1 + p_0) \cdot E\left[\widetilde{W}_i^{ref}\right] = \mu_M - (1 + p_0) \cdot \mu_{ref} \,.$$

Moreover, d_i^M can be used to further simplify the modified test definition in (4):

$$\begin{aligned} &H_0 \text{ (Null hypothesis)}: \quad d_i^M \geq 0 \\ &H_1 \text{ (Alternative hypothesis)}: \quad d_i^M < 0. \end{aligned} \qquad (7)$$

3.5 Statistical Test - Principles

The one-sided test in (7) can be carried out in a number of ways. Since the test aims at comparing the mean of an empirical distribution with some pre-determined value, the traditional one-sample t-test is the first option to evaluate. The only condition that needs to be checked to ensure its applicability is its requirement of the underlying distribution of the weighted differences d_i^M to be Normal. The test is then based on the fact that in this case the so-called "t-ratio"

$$t = \frac{\bar{d}^M}{s_d / \sqrt{J}}, \qquad (8)$$

where $\bar{d}^M$ and s_d are, respectively, the arithmetic mean and standard deviation of $\{d_i^M\}_{i=1}^J$, has a t-distribution with J-1 degrees of freedom. The null hypothesis in (7) can be rejected if the value of the t-ratio is "too small", i.e., if it falls below the required quantile of the t-distribution, as presented in **Figure 1** (here, for 95% level of confidence, this quantile is -1.6787), making it unlikely that d_i^M exceeds zero.

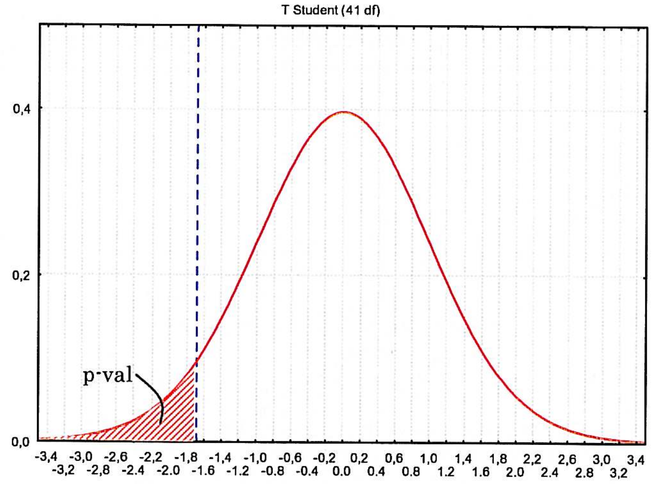

Figure 1: *t*-Test : Rejection Rule of H_0

Alternatively, if the assumption of Normality can either not be verified, or contradicts some aspects of the task at hand, the Wilcoxon rank sum test can be used to evaluate whether two samples – reference data, and data based on alternative measurement methods – come from the same population. In this case the test could be based on a a null hypothesis obtained from (5): the distributions of $\widetilde{W}^M$ and $(1+p_0)\widetilde{W}^{ref}$ are equal.

This test is not used for the present analysis as, firstly, the Normality assumption for d_i^M can be verified, and secondly, due to the proposed measurement techniques, observations gathered using the reference method and either of the two reference methods are not independent.

3.6 *t*-Test - Results

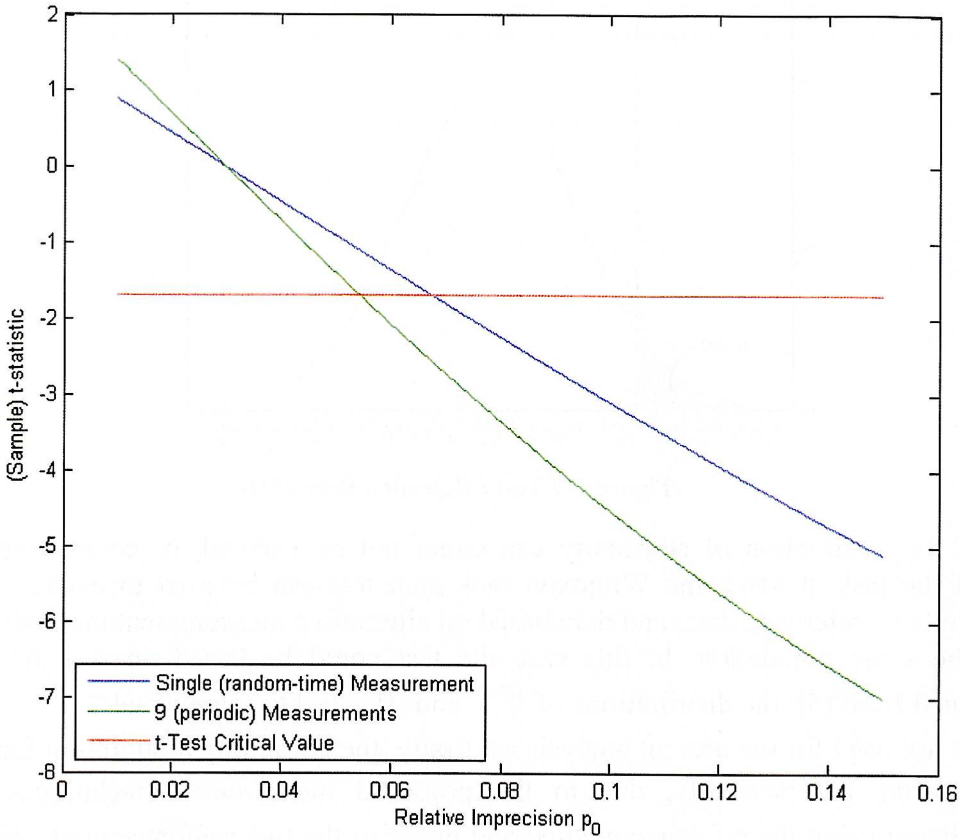

Figure 2: *t*-Ratios, Relative Imprecision p_0, and Critical Values

Additional statistical analyses (quantitatively, using the Wilcoxon rank-sum test described above, and qualitatively, using QQ-plots, both which are presented here for the case p_0=0) suggest that the differences d_i^M are Normal:

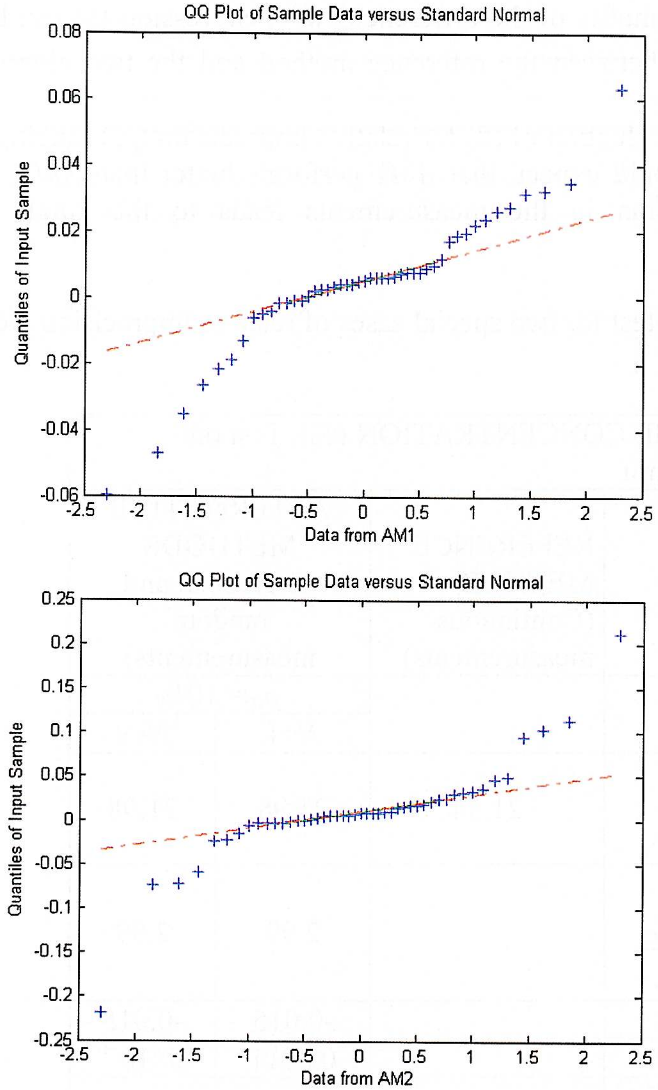

Figure 3: QQ-Plots

The scatter plots indicate that the Normal distribution fits well the bulk of the data, but the tails appear to be somewhat heavier than they would have been if Normality was true. To test whether this leads to abandoning the conclusion that the constructed differences d_i^M are Normal, a quantitative analysis is proposed. The Wilcoxon test as described above and applied to the two datasets (by simulating two independent sets of Normal random variables with means and variances equal to the means and variances of the differences d_i^M) produces the following results:

Method	p-Value (with p_0=10%)
AM1	0.4679
AM2	0.5502

Table 1 : Wilcoxon Test (for Normality)

That is, the null hypothesis that empirical probability distributions being equal to the Normal cannot be rejected.

Having established Normality of the differences d_i^M, expression (8) can be used to test whether the differences between the reference method and the two alternatives are significant.

Figure 2 presents the evaluation of (8) for relative imprecision (p_0) ranging from 1% to 15%. It shows, as one would expect, that *AM*1 performs better than *AM*2. However, allowing for 10% imprecision in the measurements leads to the single (random) measurement being accepted.

Detailed results of the *t*-test for two special cases of relative imprecision are given in the following table:

W, METHANE CONCENTRATION (%). Test on uncertainty limit			
	REFERENCE METHOD (Continuous measurements)	ALTERNATIVE METHODS (Periodical and random measurements)	
		$p_0 = 10\%$	
		N=1	*N*=9
Wch4 (Weighted mean)	21.34	21.98	21.98
Error (%) $100 \cdot \frac{\mu_M - \mu_{ref}}{\mu_{ref}}$	-	2.99	2.99
Mean (di)	-	-0.015	-0.015
Variance (di)	-	0.0011	$5*10^{-4}$
J (number of days in the studied period)	47	47	47
Student *t*-ratio	-	-3.0979	-4.5255
df	-	46	46
Conclusion	-	H_0 rejected	H_0 rejected

Table 2: Test Details

CONCLUSIONS OF THE ANALYSIS

According to the performed statistical tests in the studied period (March 2008 – July 2008) the conclusions are as follows:

The uncertainty of methane concentration estimation is lower than 10% (at 95% confidence level) for periodical measurements of *N*=9 data per day. Measurements are taken once every hour between 7:00 and 15:00.

The uncertainty of methane concentration estimation is lower than 10% (at 95% confidence level) for a single measurement made at a random point in time between 7:00 and 15:00.